Comment on "Coherent rho(0) Photoproduction in Bulk Matter at High Energies"

Rogers, T.C.; Strikman, M.

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In a recent article [1] an interesting observation was made that ultrahigh energy (UHE) photons, with energies as high as $E_\gamma \sim 10^{24}$ eV, interact coherently with bulk matter. Based on the Glauber model and extrapolations of the model of [2], the authors argued that half of the total cross section in this limit is due to the coherent production of ρ^0 mesons (the rest are purely inelastic interactions). Higher mass hadronic contributions to the photon wave function are explicitly neglected though already at $E_\gamma \sim$ 20 GeV they contribute about 40%–50% to the total cross section of the photon interactions with medium and heavy nuclei [3]. Here we point out that the dominant contribution at UHE likely comes from larger mass, small size $q\bar{q}$ configurations, including $c\bar{c}$ pairs.

The reason is that the small size pairs in the photon wave function, which are a small contribution at lower energies, begin to saturate the unitarity limit in the UHE limit at a wide range of impact parameters. It was shown in [4] that interactions of very small size components actually dominate at the energy scales ($\approx 10^{20}$ eV) considered in [1].

The total cross section for real photons interacting hadronically with a proton target can be expressed as

$$\sigma^{\gamma p}(E_\gamma) = \sum_f \int_0^1 dz \int d^2\mathbf{d} |\psi_f(z, d)|^2 \hat{\sigma}_f(d, E_\gamma)$$

with $\psi_f(z, d)$ being the wave function of the photon for $q\bar{q}$ components of transverse size d, longitudinal momentum fraction z and flavor f. $\hat{\sigma}(d, E_\gamma)$ is the total cross section for a pair of size d to scatter off a proton. For small d, the wave function can be calculated perturbatively and behaves as $1/d$ at $d \rightarrow 0$, giving a divergent contribution to the photon wave function normalization from small size (large mass) configurations. The contribution from small sizes is, nevertheless, suppressed at lower energies because of the rapid falloff of $\hat{\sigma}(d, E_\gamma)$ as $d \rightarrow 0$. However, even for a fixed small d, the cross section eventually becomes nearly black with increasing E_γ: $\hat{\sigma}_{\rm el}(d, E_\gamma \rightarrow \infty) \approx \hat{\sigma}_{\rm inel}(d, E_\gamma \rightarrow \infty) \approx \hat{\sigma}(d, E_\gamma \rightarrow \infty)/2$. This signals that, for small impact parameters, the probability to scattering inelasticly is the maximum possible for such configurations, and implies that they should be included in the analysis. Indeed, due to the $1/d$ behavior in the photon wave function, the growth of the total photon-nucleon and especially photon-nucleus cross section with energy is driven by the increasingly large contribution from small size (large mass) configurations (see the early discussion [5]). In [4], it was found that at $E_\gamma > 10^{20}$ eV, over half of the total photon-nucleon cross section is due to $q\bar{q}$ pairs smaller than $\sim$0.25 fm. With the higher energy ($E_\gamma \approx 10^{24}$ eV) and lead target considered in [1], this number will be even smaller—closer to 0.2 fm corresponding to masses larger than $\gtrsim$3.0 GeV. The shorter coherence length of these heavier states will lead to some suppression relative to the contribution from the ρ^0 meson, but only for roughly a decade of energy. Since Ref. [1] found that ρ^0 mesons are completely coherent at $\sim 10^{23}$ eV, then the 3.0 GeV mass states will be completely coherent at the maximum energy of 10^{25} eV considered in the plots of [1]. Furthermore, the range of masses between the ρ^0 mass and 3.0 GeV also gives a larger contribution to the total cross section relative to the contribution from the ρ^0 meson alone. Thus, the dominant contribution is very likely to be from states with mass larger than the ρ^0 meson. At energies where the ρ^0 meson is coherent while heavier states are not, the small contribution from ρ^0 to $\sigma_{\rm tot}(\gamma A)$ leads to a large reduction of the rate of ρ^0 coherent production as compared to [1]. Moreover, the contribution from $c\bar{c}$ pairs are important at UHE where very small size fluctuations dominate. For a carbon target and $E_\gamma \approx 10^{21}$ eV, it was found in [4] that $c\bar{c}$ pairs contribute up to 30% of $\sigma^{\gamma p}(E_\gamma)$. This contribution will be even larger at the energies considered in [1].

To conclude, we agree with [1] that the hadronic cross section from coherent particle production at small angles will likely dominate over electromagnetic interactions in the UHE limit and be nearly equal to the inelastic cross section. At energies where coherence is valid only for the ρ^0 meson the coherent cross section of [1] is overestimated by a factor of several. With increasing E_γ, the coherent cross section approaches the value calculated in [1], but is dominated by diffraction into masses much larger than 1 GeV, which can have a large effect on the pattern of showers generated by UHE cosmic rays.

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T. C. Rogers[1,2] and M. Strikman[2]
[1]Department of Physics and Astronomy
Vrije Universiteit Amsterdam
NL-1081 HV Amsterdam, The Netherlands
[2]Department of Physics
Pennsylvania State University
University Park, Pennsylvania 16802, USA

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